CHALMERS
UNIVERSITY OF TECHNOLOGY

DEVELOPMENT OF TEST ENVIRONMENTS FOR REVERSE ASSIST

Downloaded from: https://research.chalmers.se, 2021-12-11 21:07 UTC

Citation for the original published paper (version of record):
A ASHOK, N., Jonasson, M., Sadeghi Kati, M. et al (2021)
DEVELOPMENT OF TEST ENVIRONMENTS FOR REVERSE ASSIST FUNCTIONS AS APPLIED

N.B. When citing this work, cite the original published paper.

research.chalmers.se offers the possibility of retrieving research publications produced at Chalmers University of Technology.
It covers all kind of research output: articles, dissertations, conference papers, reports etc. since 2004.
research.chalmers.se is administrated and maintained by Chalmers Library

(article starts on next page)

DEVELOPMENT OF TEST ENVIRONMENTS FOR REVERSE ASSIST FUNCTIONS AS APPLIED TO AN A-DOUBLE VEHICLE COMBINATION

NRUPATHUNGA ASHOK
M2, Chalmers University of Technology, Sweden

MATS JONASSON
S2, Chalmers University of Technology, Sweden

MALIHEH SADEGHI KATI
S2, Chalmers University of Technology, Sweden

AKHIL SRINIVAS
M2, Chalmers University of Technology, Sweden

VIKRAM PARSHETTI
M2, Chalmers University of Technology, Sweden

ANAND PRABHU
M2, Chalmers University of Technology, Sweden

PRATHAM JAIN
M2, Chalmers University of Technology, Sweden

LOHITH REDDY
M2, Chalmers University of Technology, Sweden

Abstract

High-capacity transport vehicles reduce costs and improve efficiency. Long vehicle combinations such as an A-double combination vehicle (Tractor + semitrailer + dolly + semitrailer) improve transportation efficiency but they are extremely difficult to manoeuvre in tight spaces and in the reverse direction. This document summarizes developing environments to test reverse assist functions as applied to the A-double combination vehicle. These environments create a rapid prototyping platform consisting of a virtual and a scaled environment to test and validate controller concepts. The behaviour of the plant model in the virtual environment, the scaled vehicle model and the plant model in VTM (Volvo Truck Model) are studied and compared. A proportional controller is developed to test the environments and evaluate the process of concept development using the rapid prototype platform. The controller performance is evaluated and a possibility of incorporating integral controller is discussed.

Keywords: Test Environments, A-double, Heavy Vehicles, Rapid Prototype

1. Introduction

This particular project deals with A-double combination vehicles (briefly denoted as the A-double) which are very transport efficient but need special solutions to certain practical manoeuvering problems. The A-double consists of a tractor pulling a semi-trailer with a dolly and another semi-trailer behind it. It is used to increase freight capacity and improve efficiency. The A-double has a total of three pivot points, shown in Figure 1. The project aims to aid in developing a feasible solution to one such problem where the A-double is facing difficulties in reversing into the Gothenburg container harbour.

Figure 1 – Scaled model of the A-double combination used in the project.

The prime reason for difficulty in reversing a long articulated vehicle is due to multiple articulation points and the lack of visibility of the rear end of the combination. The non-holonomicity and the instability of the system make reversing a long articulated vehicle a complex problem. Previously some research work has been done to develop similar support systems, like Matsushita et al[1] but for the case of on-axle hitching and J. Morales et al[2], where two trailer combinations have been considered. Some studies have been conducted to linearize the system as presented in [3] and on non-linear approach based on Lyapunov techniques as presented in [4]. A cascaded approach is studied by Evestedt et al.[5] and a method based on fuzzy controllers is studied in [6]. The control strategy applied in this paper consists of a Human Machine Interface (HMI) that behaves as a path generator and an algorithm based on proportional control is used for path following. A PI controller is also briefly discussed.

2. Background

The A-double is employed in Sweden as a part of the AutoFreight[7] project. The A-double transports freight arriving at the Gothenburg container harbour to the intended destination. The A-double is hard to manoeuvre in the reverse direction and the driver has a difficult time backing up the combination into the designated slot specially during heavy traffic at the harbour. This can be overcome by detaching the combination outside the harbour and driving the semi-trailers one at a time for loading. This increases loading time and decreases efficiency. In order to improve loading and unloading efficiency and decrease work-related stress induced on drivers, a driver assist function needs to be developed. The objective of this work is to reduce function development time and costs by creating test environments that aid in rapid prototyping. The basic requirement of the assist function is to aid the driver in reversing the A-double to the desired loading bay while avoiding jack-knifing[8]. A plan view of the loading and unloading area and the function requirements are shown in Figure 2.

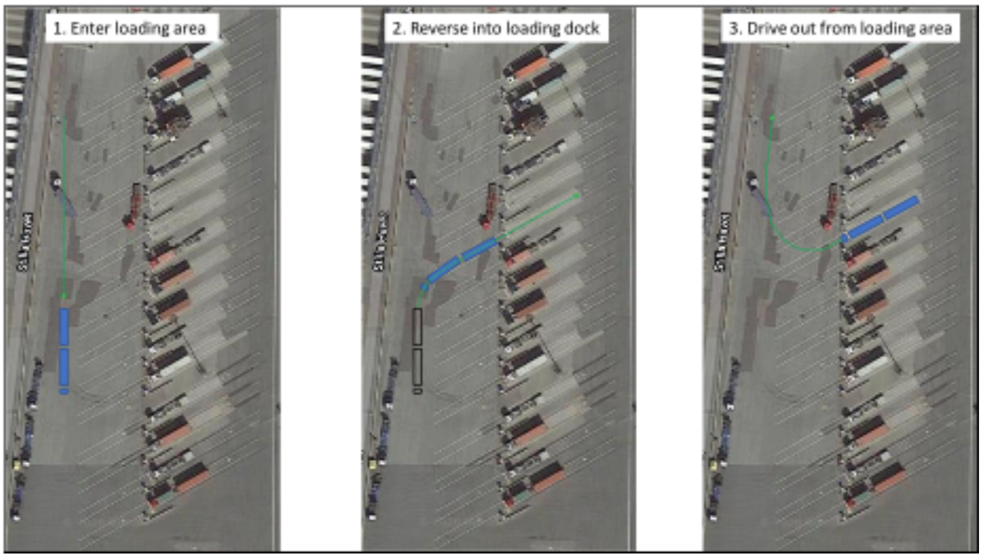

Figure 2 – Function requirement description.

3. Limitations

While developing a solution for the above stated problem, some limitations were considered. As the current project is in collaboration with the Autofreight project, the limitations described here are specific to this project and are not limited to the ones listed here. The harbour is a high-security area and any employment of a plan view camera that shows the live layout of the harbour is not allowed. The driver must stay inside the vehicle when reversing. The use of multiple sensors to perceive the environment to develop a high level autonomous solution is limited as the trailers and dolly are modular. The array of sensors available are listed below.

Table 1 – Sensors available on the combination

Sensor	Location
Articulation angle sensor	Pivots 1, 2 and 3
Global Positioning System (GPS)	Tractor
Rear view camera	Rear of trailer 2
Steering wheel angle sensor	Tractor
Vehicle speed sensor	Tractor
Inertial Measurement Unit (IMU)	Tractor

4. Test Environments

As autonomous/semi-autonomous functions are becoming more common and necessary in automotive applications, it is essential to decrease the amount of time and cost associated with the development of these functions. This will be more crucial for heavy and long vehicle combinations such as the A-double which require a higher degree of preparation and planning if the functions are to be tested on the real vehicle. Low velocity manoeuvres during loading and unloading of these long combination vehicles contribute to major losses in efficiency. In order to rapidly evaluate and develop functions to assist in these low velocity manoeuvres, testing needs to be made easier and quicker. In order to achieve this, two test environments were chosen to be developed after careful considerations of savings in time, cost and the ease of access. The first is a virtual environment that is used for preliminary tests in an ideal environment to verify function behaviour. The second is a scaled environment that uses a scaled prototype remote control (RC) vehicle to test control algorithms in an environment with a higher degree of fidelity.

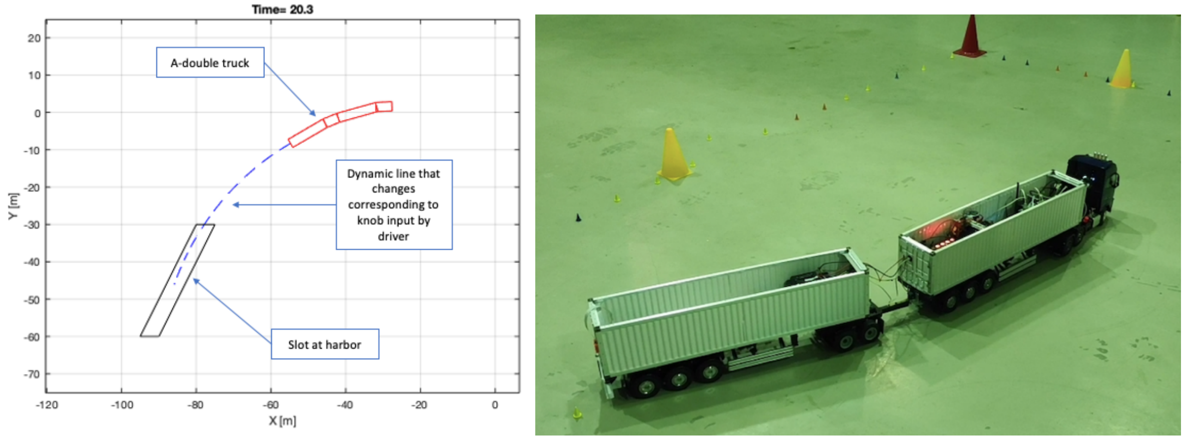

Figure 3 – The virtual test environment (left) and the scaled test environment (right)

4.1 Virtual Test Environment

The virtual test platform is a Simulink/MATLAB environment that uses a single-track kinematic vehicle model. As the studied velocities are low, the roll and pitch motions are ignored. The model provides the articulation angles as the outputs and requires the velocity and steering wheel angle as the inputs. The virtual environment is ideal and does not consider disturbances and noise that are always present in a system and makes the system behave in an unpredictable fashion. The vehicle model does not take into account wheel scrub, tyre slip, axle loads, sensor noise, road unevenness and is simplified in many such aspects. A snapshot of the controller being tested in the virtual environment is shown in Figure 3 and Figure 4 shows the schematic of the bicycle model of the A-double combination and some of the variables used in the rest of the section.

In the Simulink environment, the vehicle coordinate system is aligned with the global system with p1 on the global origin at start of simulation. The global system follows a conventional coordinate system. The three pivot points denoted as p1, p2 and p3 are considered as the reference points and are used to track the orientation and position of the vehicle. Each of the units are numbered from 1 (truck) to 4 (second semitrailer). The velocity variables are named as $v_{[link\ number][velocity\ component][pivot\ point]}$. The velocity of the truck is v_{1xp1} and is considered as a driver input. The yaw angles of the units are φ_{1-4}, the articulation angles are θ_{1-3}, the side slip angles of the pivot points are β_{p1-p3} and the steered road wheel angle is δ. The steering angle is positive counter-clockwise and the articulation angles are positive clockwise. The equations of motion are derived as follows:

$$v_{1yp1} = v_{1xp1}\frac{b1}{L1}\tan\delta \tag{1}$$

$$\dot{\varphi}_1 = \frac{v_{1xp1}}{L1}\tan\delta \tag{2}$$

$$\dot{\varphi}_2 = \frac{v_{1xp1}}{L2}(\sin\theta_1 + \cos\theta_1)\frac{b1}{L1}\tan\delta \tag{3}$$

$$\dot{\theta}_1 = \dot{\varphi}_1 - \dot{\varphi}_2 \tag{4}$$

$$\beta_{p1} = \tan^{-1}(\frac{b1}{L1}\tan\delta) \tag{5}$$

$$v_{2xp1} = v_{1xp1}\cos\theta_1 - v_{1yp1}\sin\theta_1 \tag{6}$$

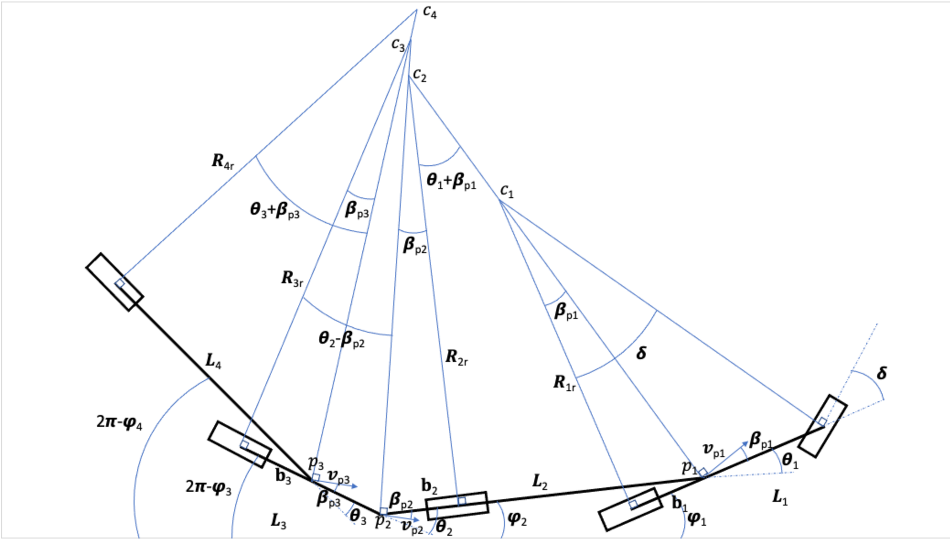

Figure 4 – Kinematic model diagram

$$v_{2yp1} = v_{1yp1}\cos\theta_1 + v_{1xp1}\sin\theta_1 \tag{7}$$

$$\dot{\varphi}_3 = \frac{v_{2xp1}}{L3}(\sin\theta_2 - \frac{b2}{L2}\cos\theta_2\tan(\theta_1 + \beta_{p1}) \tag{8}$$

$$v_{2yp2} = v_{2xp1}\frac{b2}{L2}\tan(\theta_1 + \beta_{p1}) \tag{9}$$

$$v_{3yp2} = v_{2xp1}\sin\theta_2 - v_{2yp2}\cos\theta_2 \tag{10}$$

$$\beta_{p2} = \tan^{-1}(\frac{b2}{L2}\tan(\theta_1 + \beta_{p1})) \tag{11}$$

$$v_{3xp2} = v_{2xp1}\cos\theta_2 + v_{2yp2}\sin\theta_2 \tag{12}$$

$$\dot{\theta}_2 = \dot{\varphi}_2 - \dot{\varphi}_3 \tag{13}$$

$$\dot{\varphi}_4 = \frac{v_{3xp2}}{L4}(\sin\theta_3 + \frac{b3}{L3}\cos\theta_3\tan(\theta_2 - \beta_{p2})) \tag{14}$$

$$v_{3yp3} = v_{3xp2}\frac{b3}{L3}\tan(\theta_2 - \beta_{2}) \tag{15}$$

$$v_{4xp3} = v_{3xp2}\cos\theta_3 - v_{3yp3}\sin\theta_3 \tag{16}$$

$$v_{4yp3} = v_{3yp3}\cos\theta_3 + v_{3xp2}\sin\theta_3 \tag{17}$$

$$\dot{\theta}_1 = \dot{\varphi}_3 - \dot{\varphi}_4 \tag{18}$$

4.2 Scaled Test Environment

The scaled test environment is a 1:14 RC model that has been built by REVERE[9] and is equipped with multiple small computers, articulation angle sensors, cameras, inertial measurement unit (IMU), vehicle velocity sensors and WiFi connectivity. The scaled test platform runs on OpenDLV[10], which is the software platform used at Chalmers University and REVERE to develop autonomous functions. Control algorithms that behave as expected in the virtual environment can be further tested and verified on the scaled platform that introduces factors such as noise, surface unevenness, axle loads and other actuator limitations that make the test results closer to reality. The plant model is shown in the scaled environment in Figure

5. The Next Unit of Computing (NUC) on the RC vehicle is similar to computers found on the real tractor, it stores and runs the control algorithm. The RC model used in the scaled environment is shown in Figure 3 and the hardware configuration diagram is shown in Figure 6 and hardware used in the scaled model is listed in Table 2.

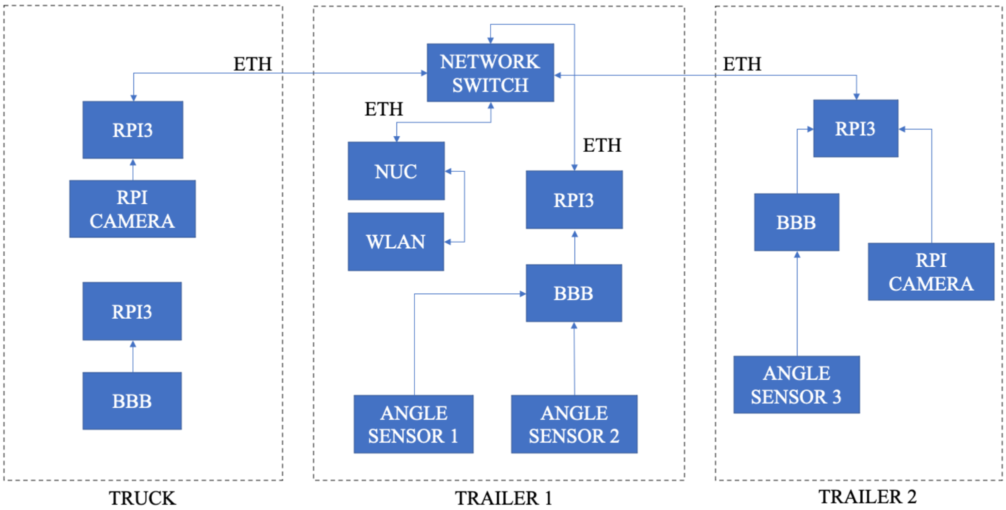

Figure 4 – Hardware configuration diagram

Table 2 – Sensors available on the combination

Hardware	Location
Groove 12-bit magnetic rotary sensor (Articulation angle)	Pivot points 1,2 and 3
Raspberry pi 3 (RPI3)	Tractor, Trailer 1 and Trailer 2
Raspberry pi camera	Tractor and Trailer 2
Inertial Measurement Unit(IMU)	Tractor, Trailer 1 and Trailer 2
Beaglebone Blue (BBB)	Tractor, Trailer 1 and Trailer 2
Next Unit of Computing (NUC)	Trailer 1

5. Model Validation

The plant models in the virtual environment (kinematic vehicle model) and the scaled environment (RC vehicle) have been compared to Volvo Truck Model (VTM), which is a high fidelity plant model developed and used by Volvo Group for dynamic simulations. The vehicle models using the VTM library have been validated against real test data and proved to be sufficiently accurate in simulating the actual vehicle behaviour[11]. VTM considers many factors neglected in the Kinematic model used in the virtual test environment. The behaviour of the three models, especially the articulation angles are studied to validate the virtual and the ccaled model with VTM. A step steer steering manoeuvre of 15 degrees road wheel angle at 2.7 m/s (forward motion) is conducted on all three vehicle models (scaled down 14 times to 0.19 m/s on the scaled model) and the articulation angles at each pivot point are recorded against time.
The articulation angle responses of the three models to step steer are shown in Figure 5. From the plots, it can be seen that the models follow a similar trend. The virtual environment and VTM have very similar responses except for the case in the second articulation angle (the angle

between the first semitrailer and dolly) where VTM reaches higher articulation angles. The minor variations in response between the two models can be attributed to the approximations made in the virtual model and the small differences in length of the units used in the A-double where VTM has slightly different distances between axles and does not collapse multiple axles into a single axle.

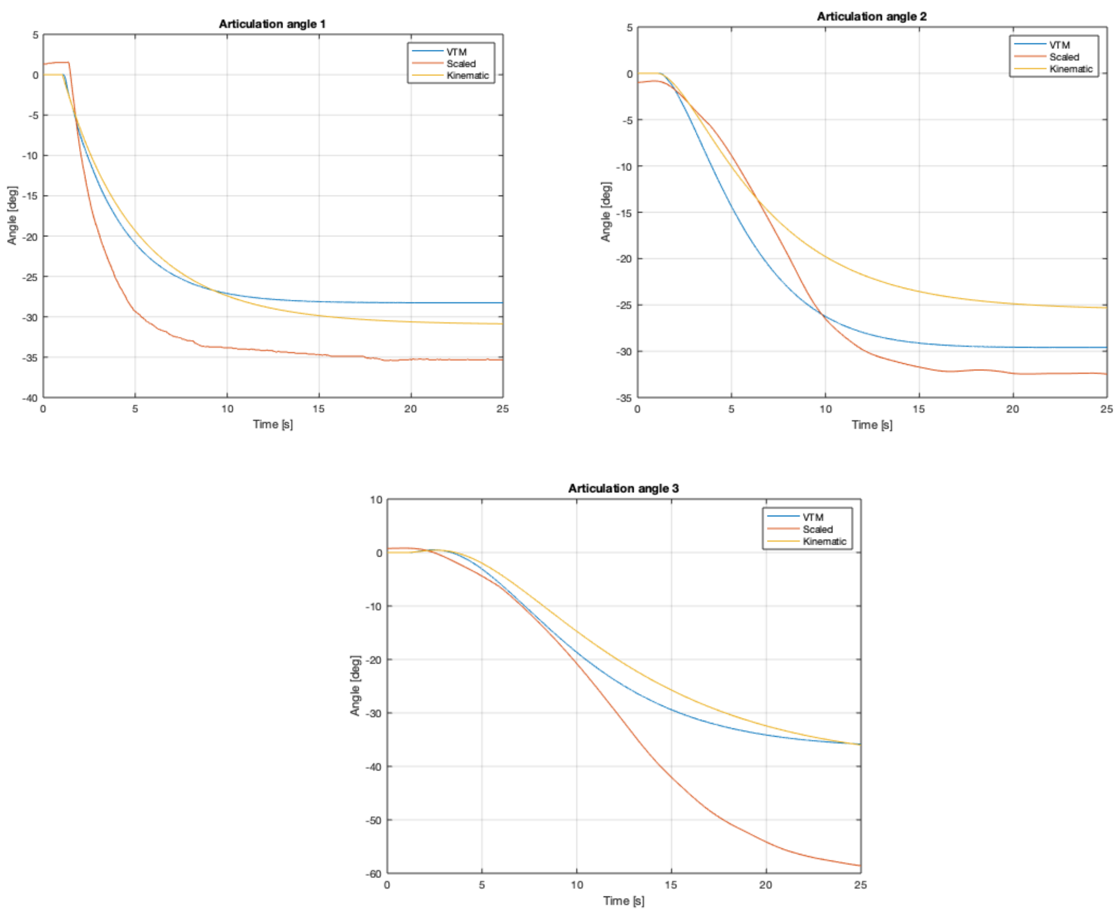

Figure 5 – Articulation angle response to step steer in the three environments

The length of the units used in the Virtual model are scaled up from the Scaled model for better conformity between the models that make up the rapid prototype environment.
The scaled model has a higher deviation in response compared to the other two models. This could be due to the actual road wheel angle being slightly greater than what is requested by the controller due to the open-loop steering system and the compliance in the model being a major factor. Further studies need to be conducted to be certain about the factors causing the deviation.

6. Control Concept

The control function is designed to be intuitive and transforms the vehicle combination with multiple pivot points into a pseudo rigid vehicle. This is achieved by constantly monitoring and adjusting the various articulation angles using the steered wheels. A simple path generation algorithm and a proportional controller are used to build a prototype of the revering assist function. A schematic of the function description is shown in Figure 6.

6.1 Path Generation

The control block requires the radius of curvature of the reference path considered which is provided by the driver using a knob. The knob is part of the Human Machine Interface (HMI) used for path generation and correction by the driver. The HMI used and a snapshot with the rear view monitor (bottom left of the image on the right) while conducting an experiment is shown are Figure 7. The rear view monitor displays the path which the driver monitors. The driver is used to close the control loop and is utilized to perceive the environment and correct errors. This reduces the complexity of the controller and the sensors required.

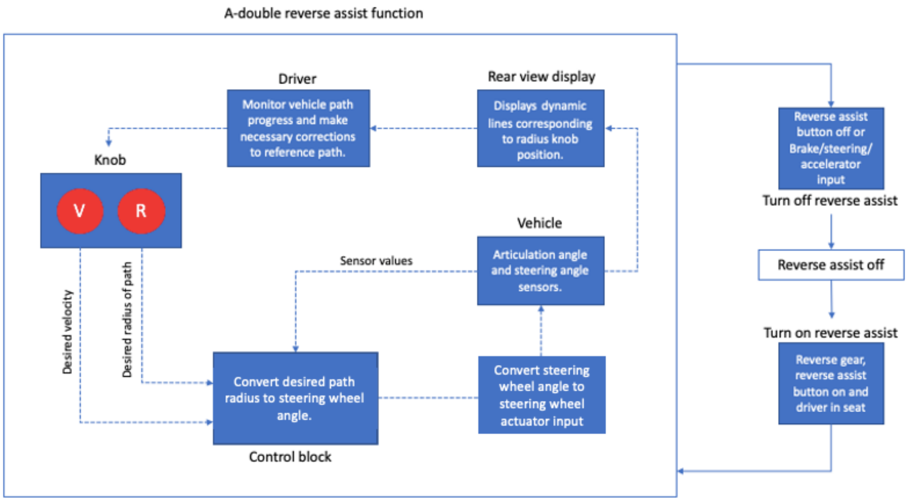

Figure 6 – Control concept schematic

6.2 Path Following

A proportional controller is used to follow the path generated by the driver. The three articulation angles are considered dependent on the previous articulation angle with the steered wheels affecting the first pivot point which then translates this effect downstream towards p3 with some delay. By using the path to be followed and the velocity of the vehicle as driver inputs, the required articulation angle at p3 (between the dolly and the second semitrailer) is calculated. The error at each articulation angle is corrected with the previous articulation angle going upto the steered wheels. The proportional gains are weighted with the highest priority to error in p3. The response of the proportional controller in the Virtual environment with a velocity input of -2.7 m/s and the radius input of 70m was studied. The plots obtained from the study are shown in Figure 8.

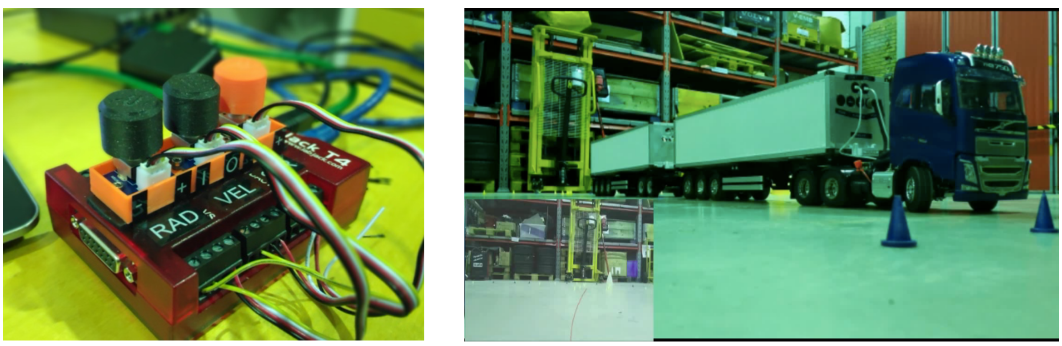

Figure 7 – The HMI used in the experiments

The A-double takes about 15 seconds to reach steady state and a steady state error due to the proportional controller can be noted. The change in phase or delay as the signal flows downstream from the steered wheels to p3 can be seen to increase with distance from steered wheels.

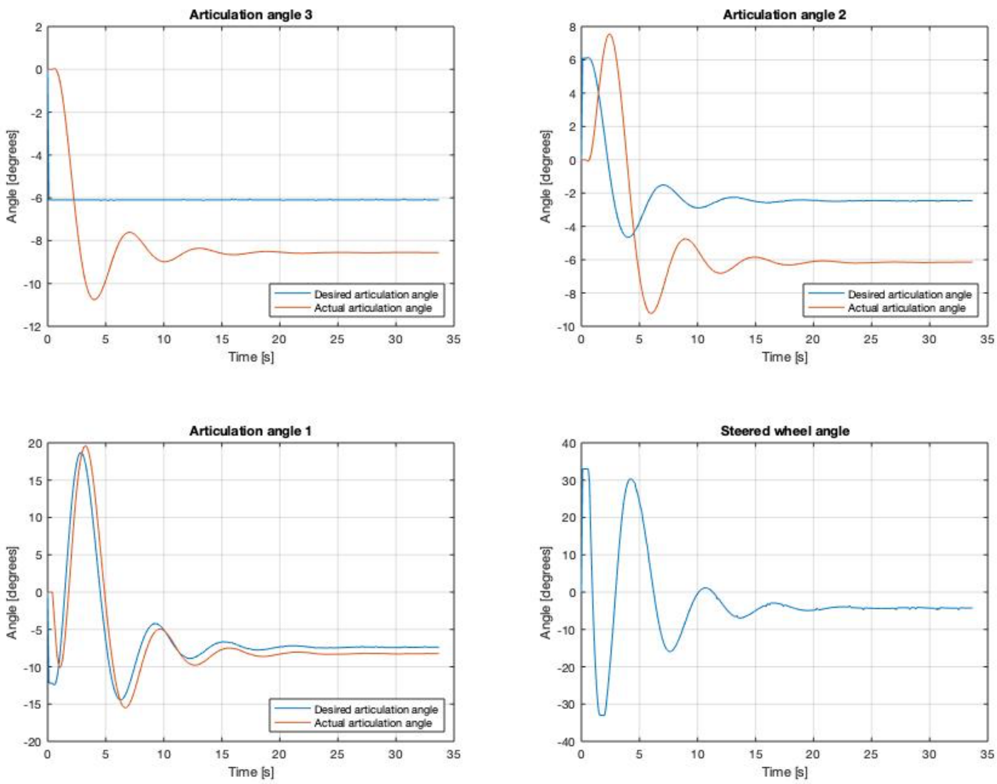

Figure 8 – Proportional controller response

6.3 Testing and Results

Multiple tests of reversing the scaled model into parking slots like the one at the harbor were conducted. It was observed that the minimum radius of the path curvature that the controller could successfully follow repeatedly was 5m (70m when scaled up) on the Scaled model, where as it could successfully follow a path radius of 40m (2.85m when scaled down) on the Virtual model. This seems reasonable as the Scaled model had many factors such as surface unevenness, lack of tire grip, axle loads etc. affecting the performance. The dolly on the Scaled model was observed to be very sensitive to surface unevenness and would cause the combination to jack-knife at a path radius of lower than 5m (70m when scaled up). The deviation in behaviour is acceptable as the driver can monitor the progress and make corrections. One such reversing maneuver conducted on the Scaled model was recreated in the Virtual environment and the articulation angle response and steered wheel angles are shown in Figure 9. The two environments follow a similar trend and behave reasonably alike. As seen in earlier simulations, the phase or delay increases with distance from the steered wheels, more so in the scaled model. As the velocity of the vehicle in the Scaled environment is an input from the driver, it is not constant and may cause a slower response times. Lack of grip between the tires and the surface also cause slower response. Actuator limitations, kinematics and compliance of the scaled vehicle also influence the behaviour of the Scaled environment from the Virtual environment. More studies need to be conducted to ascertain the extent of their influence on the behaviour. Studies conducted so far show that the process of concept development in the rapid prototyping platform saves time and costs while still providing sufficiently accurate initial estimates of the performance of controllers.

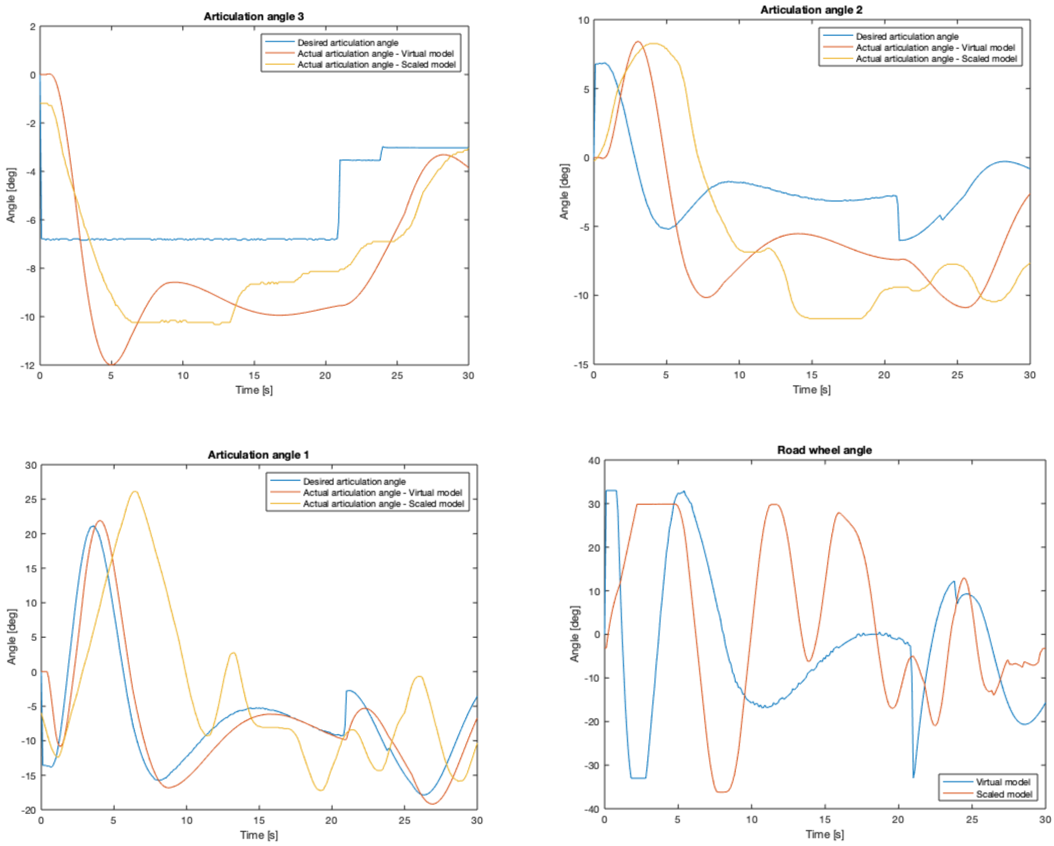

Figure 9 – Articulation angle response of reversing manoeuvre

6.4 PI Controller

A PI controller was briefly studied to see the improvement in performance by eliminating the steady state error. A reversing maneouvre at -2.7m/s and 70m path radius was conducted on the improved controller and the response is shown in Figure 10. Since the orientation of the rear of the second semitrailer governs the path taken by the combination, the integral gains were tuned such that the steady state error at p3 is removed. As seen from the plots, the steady state gain is removed but this increases the settling time of the system.

7. Future Work

The PI controller can be further tested and validated on the scaled model. A derivative controller can be incorporated to increase settling time of the system. More work can be conducted on understanding the effects of physical actuator limitations and compliance on the performance. More analysis of the current controller may be conducted to better understand the behaviour of the environments and the factors affecting it.
At the time of writing the paper, work is being conducted to test the controller on the real vehicle combination. These tests would then complete the process of rapid prototyping of control concepts as developed in the project.

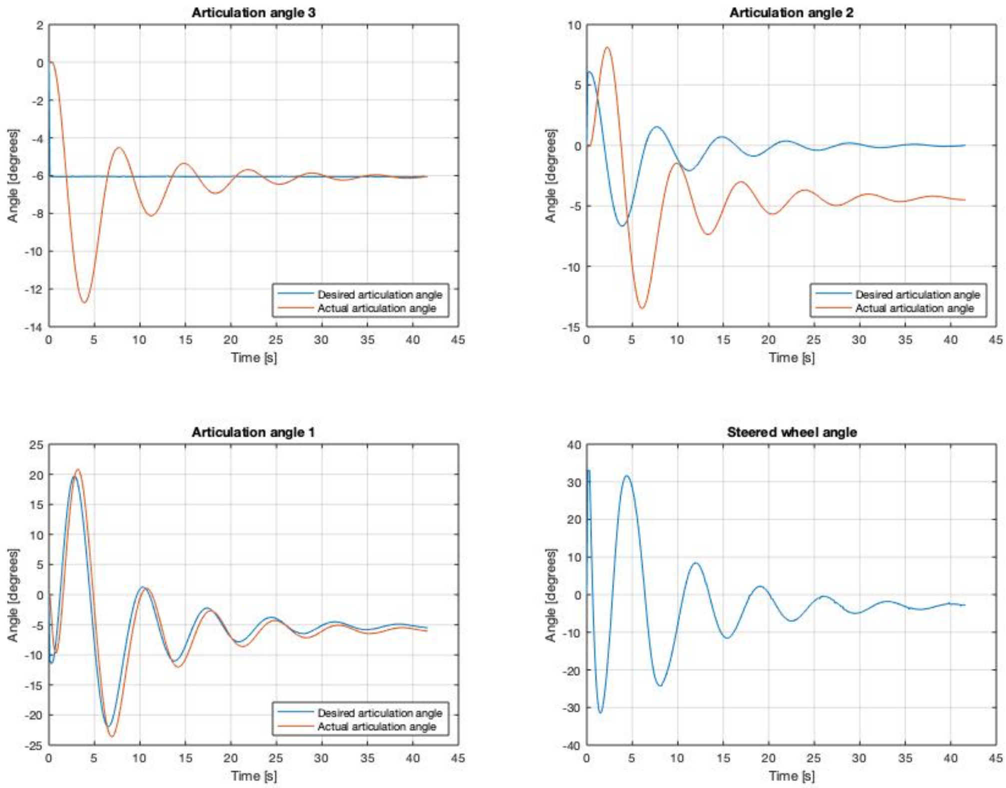

Figure 10 –PI controller response

8. References

[1] Kouki Matsushita, and Toshiyuki Murakami, Backward Motion Control for Articulated Vehicles withDouble Trailers Considering Driver's Input, IECON - 32nd Annual Conference on IEEE IndustrialElectronics, 2006.

[2] J. Morales et al, Driver assistance system for backward maneuvers in passive multi-trailer vehicles,Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, 2012.

[3] C. Altafini, A. Speranzon, and B. Wahlberg. A feedback control scheme for reversing a truck and trailer vehicle. *Robotics and Automation, IEEE Transactions on*, 17(6):915–922, 2001.

[4] A. Astolfi, P. Bolzern, and A. Locatelli. Path-tracking of a tractor- trailer vehicle along rectilinear and circular paths, a lyapunov- based approach. *Robotics and Automation, IEEE Transactions on*, 20(1):154–160, 2004.

[5] Niclas Evestedt, Oskar Ljungqvist and Daniel Axehill ,"Path tracking and stabilization for a reversinggeneral 2-trailerconfiguration using a cascaded control approach".

[6] S.-G. Kong and B. Kosko. Adaptive fuzzy systems for backing up a truck-and-trailer. *Neural Networks, IEEE Transactions on*, 3(2):211– 223, 1992.

[7] Highly Automated Freight Transports EUTS (AutoFreight), https://research.chalmers.se/en/project/8213

[8] "Jackkinfing", https://en.wikipedia.org/wiki/Jackknifing

[9] "Chalmers REVERE", https://www.chalmers.se/sv/forskningsinfrastruktur/revere/Sidor/default.aspx

[10] "OpenDLV Software Architecture", https://www.chalmers.se/en/researchinfrastructure/revere/Resources/ Pages/OpenDLV.aspx

[11] P. Sundstrom and L. Laine, "Validation of VTM model of tractor 4x2 with semi- ¨ trailer using winter test results from arjeplog 2111w11 p2685," Tech. Rep., 2012.